

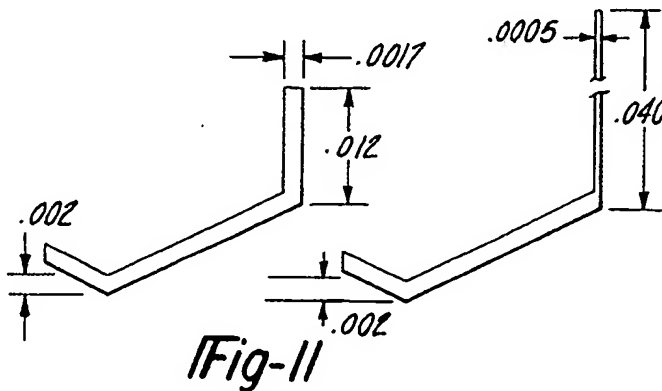
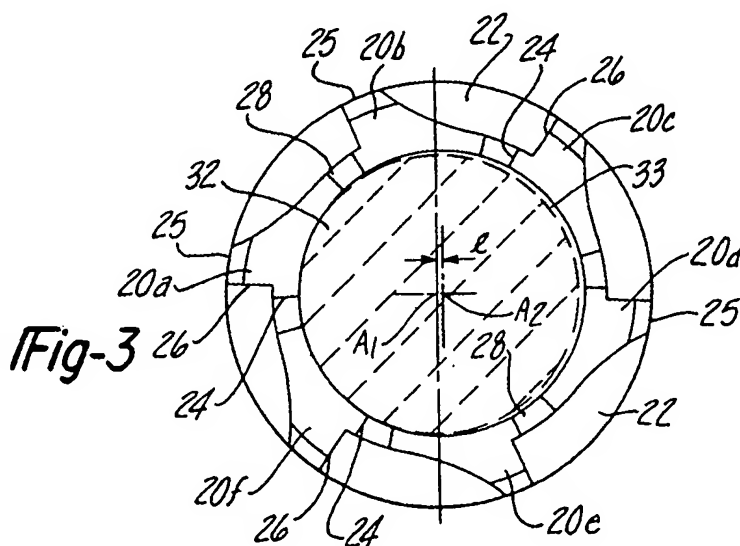
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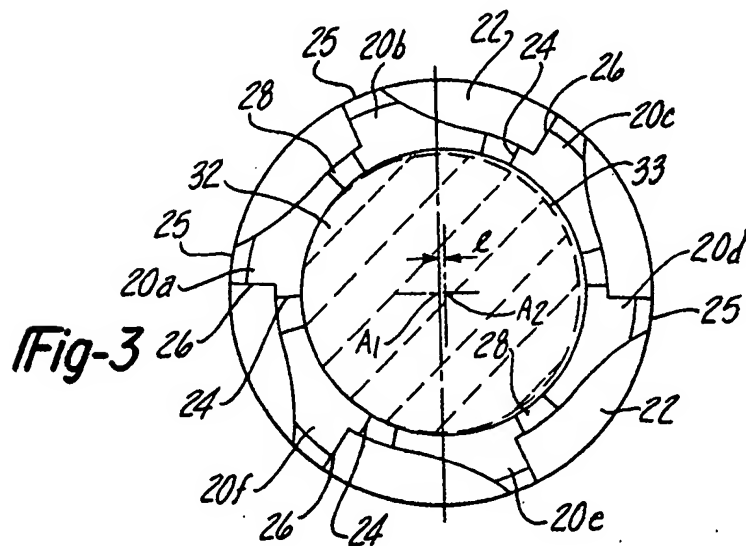
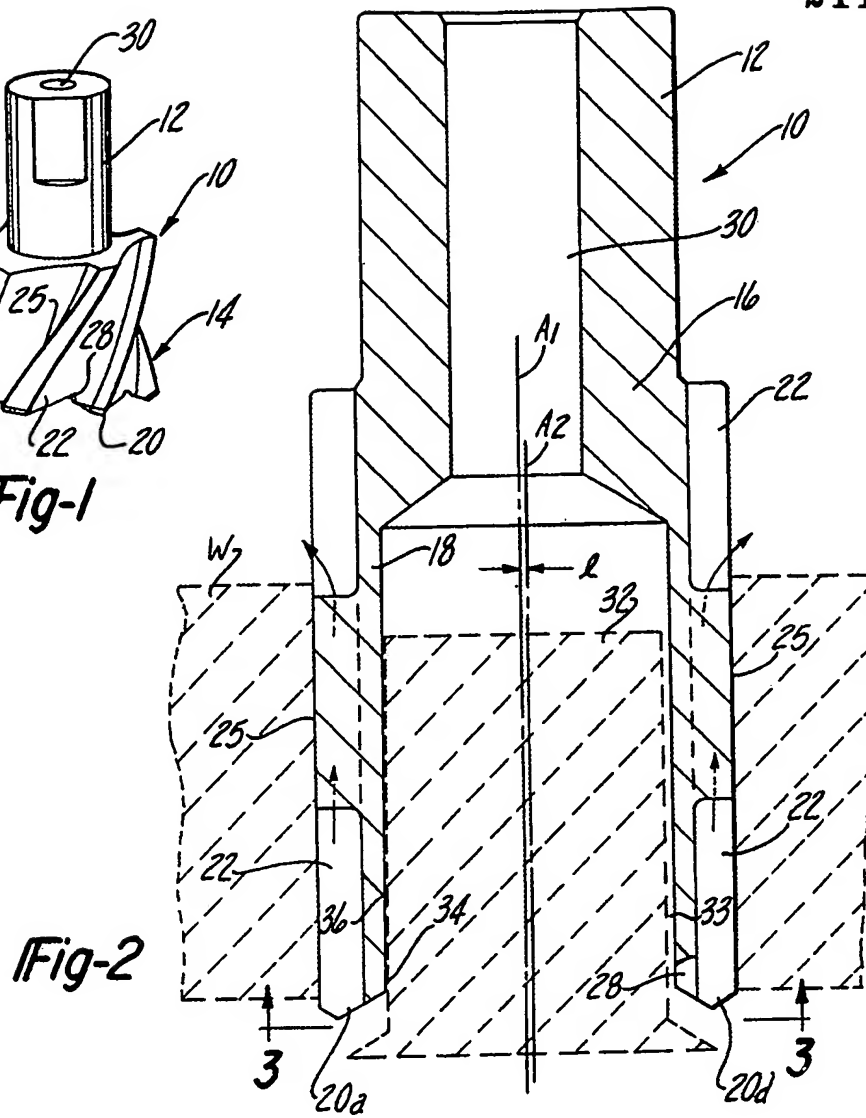
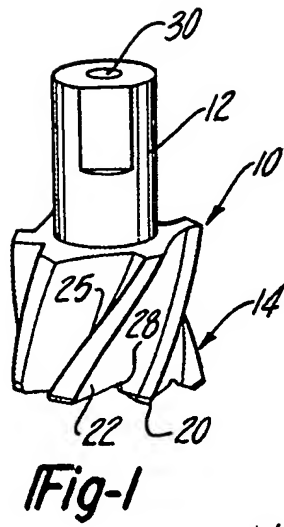
(54) Annular hole cutter

(57) In a cutter of the kind described in GB-A-2078144, wherein the outer periphery of an annular cutter is accurately concentric with the central rotary axis A<sub>1</sub> of the cutter and the

inner periphery of the cutter is eccentric to a predetermined amount (e) with respect to the outer periphery of the side wall, the eccentricity (e) is such that the radial thickness of the chips (Figure 11) cut from the slug by the inner edges of the wider teeth is at least 0.025 mm.



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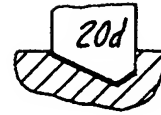
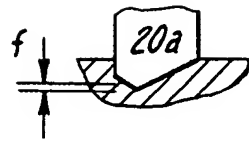


Fig-4

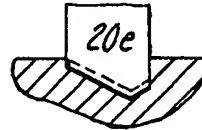
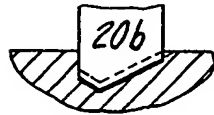


Fig-5

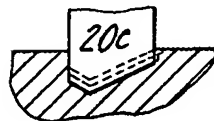


Fig-6

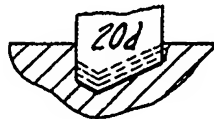


Fig-7

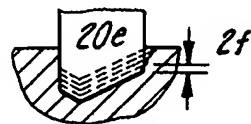


Fig-8

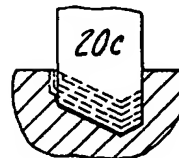
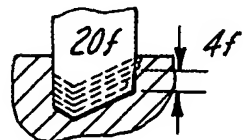


Fig-9

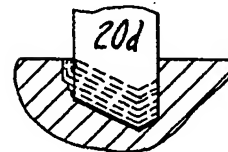
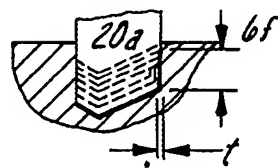


Fig-10

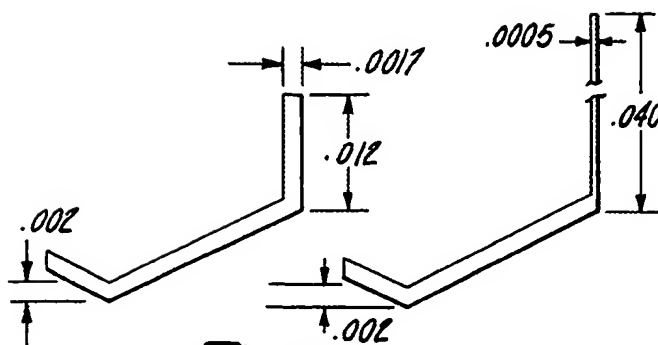


Fig-11

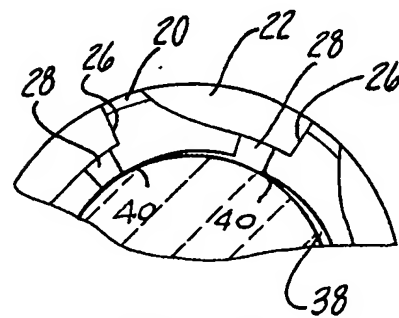


Fig-12

# **SPECIFICATION** **Annular hole cutter**

This invention relates to an annular hole cutter.

When cutting a hole with an annular cutter the  
5 cutter teeth cut a circular groove in the workpiece  
which forms a central cylindrical slug within the  
cutter. In order to prevent binding of the slug  
within the cutter and to provide a coolant  
passageway within the cutter which extends  
10 down to the cutter teeth, cutters are frequently  
designed to provide clearance spaced between  
the inner periphery of the cutter side wall and the  
outer periphery of the central slug. With cutters in  
the form of a thin circular saw blade this  
15 clearance can be obtained in the manner shown  
in U.S.A. Patent No. 3,559,513 where selected  
teeth around less than one-half the circumference  
of the cutter are bent inwardly slightly. However,  
cutters used for cutting holes in thick metal  
20 workpieces, as distinguished from sheet metal,  
are not in the form of a saw blade bent into  
circular shape, but are machined from bar stock  
and have a relatively thick side wall. With cutters  
of the latter type, clearance between the inner  
25 periphery of the cutter side wall and the central  
slug is normally obtained by grinding an axial  
taper on the inner periphery of the cutter side  
wall. Normally this taper is about 0.203 mm for  
the length of the side wall.  
30 The strength of an annular cutter is normally  
primarily determined by the thickness of its fluted  
side wall. However, the efficiency of the cutting  
action normally decreases as the side wall  
thickness increases since the width of the groove  
35 cut varies in accordance with the side wall  
thickness. Where a machined annular cutter is  
provided with an axial taper on its inner periphery  
its strength is determined by the thinnest section  
of the side wall. Therefore, in an internally tapered  
40 cutter, if the cutter side wall has a predetermined  
thickness at the cutting teeth, the thickness of the  
side wall becomes progressively less towards the  
shank end of the cutter. It follows that for a cutter  
designed to cut through relatively thick stock it is  
45 impractical to provide the necessary clearance  
between the cutter and the slug by grinding an  
internal taper on the cutter.

However, even with internally tapered cutters,  
the problem of binding of the slug within the  
50 cutter is not entirely eliminated. This results from  
the fact that, as the cutter advances into the work,  
the cutter slug becomes heated and expands.  
Therefore, at the end of a cutting operation the  
diameter of the slug is normally slightly larger  
55 than the inner diameter of the side wall at the  
tooth end thereof. This results in binding of the  
slug within the cutter and frequently also results  
in tooth breakage.

In UK Patent application No. 2078144A,  
60 published on 6th January 1982, there is  
described a machined annular cutter wherein the  
desired clearance between the cutter and the  
central slug is obtained by forming the cutter so  
that the outer periphery of the side wall is

65 concentric with the central axis about which the  
cutter rotates and the inner periphery of the side  
wall is eccentric with respect to said axis. Since  
the outer periphery of the cutter is concentric with  
the central axis of the cutter, a smooth accurate  
70 hole is cut. However, since the inner periphery is  
eccentric with respect to the axis about which the  
cutter is rotated, the diameter of the central slug  
is smaller than the inner diameter of the cutter  
side wall by an amount equal to twice the  
75 aforesaid eccentricity.

An object of the present invention is to provide  
a further improved machined annular cutter which  
produces the desired clearance between the  
cutter side wall and the central slug throughout  
80 their entire length without substantially reducing  
the side wall thickness of the cutter.

A further object of the invention is to provide a  
means for determining the degree of eccentricity  
required in the cutter side wall to enable the  
85 cutter to produce the necessary clearance  
between the inner periphery of the cutter and the  
outer periphery of the central slug.

The invention will be further described, by way  
of example, with reference to the accompanying  
90 drawings, in which:

Figure 1 is a perspective view of an annular  
hole cutter of the type to which the present  
invention relates;

Figure 2 is a sectional view of a cutter  
95 embodying the present invention and showing the  
cutter as it penetrates through a workpiece;

Figure 3 is a sectional view of the cutter taken  
along the line 3—3 in Fig. 2;

Figures 4 to 10 illustrate schematically the  
100 cutting action of each tooth of the cutter shown in  
Fig. 3 as it penetrates into a workpiece;

Figure 11 illustrates schematically the  
comparison in chip size and configuration  
between two cutters having different numbers of  
105 teeth with same eccentricity; and

Figure 12 is a fragmentary end view of a  
modified form of cutter.

Referring to Fig. 1, the cutter, generally  
designated 10, includes a shank 12 and a cutter  
body 14. The cutter body 14 is of inverted cup  
shape so that, as illustrated in Fig. 2, it is defined  
by a top wall 16 and an annular side wall 18. The  
lower end of the side wall 18 of the cutter shown  
115 in Figs. 1 to 3 has six circumferentially spaced  
cutting teeth 20 thereon. The outer periphery of  
side wall 18 is formed with helical flutes 22  
which extend upwardly from between successive  
teeth 20. In the cutter illustrated the configuration  
of each tooth 20 is substantially the same as  
120 shown in my U.S.A. Reissue Patent No. 28,416.  
More specifically, each tooth 20 is provided with  
a radially inner cutting edge 24 and a radially  
outer cutting edge 26. The inner cutting edge 24  
of each tooth is staggered forwardly in the  
125 direction of rotation of the cutter relative to the  
outer cutting edge 26. Cutting edge 24 defines  
the lower end of an inner gullet 28 for directing  
chips cut by the inner cutting edge 24 outwardly  
into flute 22.

The outer periphery of shank 12 is ground so that it is concentric to the central axis  $A_1$  of the cutter to a high degree of accuracy. Preferably, shank 12 is formed with a central through bore 30 by means of which liquid coolant supplied to the arbor in which the shank is retained can be directed downwardly within the cutter to the teeth 20.

Referring now to Fig. 3 where the most important feature of the present cutter is illustrated, the outer periphery of the cutter side wall defined by the lands 25 is ground concentric to the axis  $A_1$  to a high degree of accuracy, preferably to a tolerance of  $\pm 0.05$  mm. The inner periphery of the cutter side wall 18 is ground concentric to the axis  $A_2$  to a high degree of accuracy, that is, within the same tolerance as the outer periphery of the cutter. However, the axis  $A_2$  is offset radially slightly from the axis  $A_1$ . Tests have shown that a cutter having about five to eight teeth performs very well when the axis  $A_2$  is offset from the axis  $A_1$  at least about 0.127 mm. In the drawing this radial offset of axis  $A_2$  from axis  $A_1$  is designated  $e$ . Tests have shown that with respect to surface finish, out-of-roundness and the dimensional accuracy of the hole cut, five to eight teeth produce best results in mild steel when dimension  $e$  is not less than about 0.127 mm.

In Figs. 2 and 3 the axis  $A_2$  is shown shifted to the right relative to the axis  $A_1$ . The flutes 22 are all ground to the same depth and, consequently, the tooth 20a at the left side of Fig. 3 is the widest tooth and the diametrically opposite tooth 20d is the narrowest tooth. Teeth 20b and 20c are progressively narrower than tooth 20a and teeth 20e and 20f are progressively wider than tooth 20d. It therefore follows that with respect to the central slug 32 formed as the cutter penetrates through the workpiece, the finished outer surface thereof is generated solely by tooth 20a which has the radially innermost cutting edge. The inner ends of the remaining cutting edges are all spaced radially outwardly from the finished outer surface of slug 32 as shown in Fig. 3. The arcuated clearance space 33 which results from the offsetting of axis  $A_2$  from the axis  $A_1$  provides an excellent axial coolant passage from the bore 30 in shank 12 downwardly to the cutting teeth of the cutter. In addition, as soon as the teeth penetrate through the under surface of the workpiece W, the centre slug 32 drops freely from within the cutter since its outer diameter is smaller than the inner diameter of wall 18 by an amount equal to twice the dimension  $e$ .

With the cutter described the inner surface of the cutter wall 18 will contact the finish outer surface of slug 32 theoretically only along a line in axial alignment with the radially inner end of the tooth 20a. In order to reduce frictional contact between the cutter and the slug 32 to an absolute minimum, it has been found desirable to grind the inner surface of wall 18 with a slight taper. However, this taper is relatively short in comparison to the length of wall 18. For

example, the taper, which is designated 34 in Fig. 2, terminates at the section designated 36 and has an axial extent of only about 6.35 to 12.7 mm. The extent of this taper is such that at the section 36 the diameter of the inner periphery of wall 18 is about 0.10 to 0.15 mm greater than at the lower end of the cutter. In other words, the total taper is on the order of about 0.05 to 0.75 mm.

When the six tooth cutter shown in Fig. 3 has an eccentricity of about 0.127 mm and a feed rate of about 0.30 mm per revolution (0.05 mm per tooth), the cutting action which occurs during each revolution of the cutter as it penetrates into the work is illustrated schematically in Figs. 4 to 10. In these figures  $f$  represents the feed rate per tooth and  $t$  represents the radial thickness of the chip machined from the outer peripheral surface of the central slug 32. The actual chip cut by each tooth is shown schematically as a thickened solid line at the bottom of each figure and the chips cut by the preceding teeth are shown in light broken lines above the solid lines in each figure.

As the cutter initiates the cut (Fig. 4), tooth 20a will cut the widest groove and the diametrically opposite tooth 20d will initiate the cut with a groove of the same depth, but of minimum width. Then tooth 20b will increase the depth of the groove by the same feed rate  $f$ , but with a narrower width than tooth 20a. Simultaneously tooth 20e diametrically opposite tooth 20b cuts a groove of the same depth, but slightly wider than the groove initiated by tooth 20d. As the cutter continues to rotate while being fed into the workpiece a point is reached where the inner edges of teeth 20e, 20f and 20a start to remove metal from the periphery of the centre slug that was machined by the preceding narrower teeth and, thus, produce the clearance space 33. Therefore, as shown at the left of Figs. 8, 9 and 10, the radially inner upright portions of the chips cut from the outer periphery of the centre slug by the successive teeth 20e, 20f and 20a are progressively greater in height. A similar action occurs when these teeth assume a diametrically opposite position as illustrated at the right in Figs. 5, 6 and 7. As pointed out above, the finished surface of central slug 32 is produced by the widest tooth 20a.

Based on the above explanation, it is apparent that the following relationships exist:

$$t = \frac{2e}{n}$$

where  $n$  is the number of teeth, and

$$h = nf$$

where  $h$  is the height of the upright portion of the chip machined off the peripheral surface of the central slug.

In the case of a cutter such as shown in Fig. 3 having six teeth, an eccentricity of about 0.127

mm (0.005 inch) and a feed rate of about 0.05 mm (0.002 inch) per tooth, the axial thickness of each chip is about 0.05 mm (0.002 inch) and the radial thickness of the upright chips cut by each of the teeth 20e, 20f and 20a is about 0.043 mm (0.0017 inch), the latter chips increasing successively in height from about 0.10 mm (0.004 inch) to about 0.30 mm (0.012 inch). These dimensional relationships are shown on the chip illustrated on an enlarged scale at the left of Fig. 11. A reasonably sharp cutter can cut chips in this size range with little difficulty where the workpiece is a medium carbon steel.

From the relationships stated above it follows that, all other parameters remaining the same, as the number of teeth increases, the radial thickness of the chip decreases while its height increases. For example, if the cutter has twenty teeth instead of six, the radial thickness of the chip is reduced to 0.013 mm (0.0005 inch) and the maximum height of the chip is increased to 1.0 mm (0.040 inch). For comparison purposes such a chip is shown on an enlarged scale at the right of Fig. 11.

Experience has shown that as the number of teeth increases, other parameters being constant, a point is reached where the increased radial thrust on the cutter resulting from a chip of relatively great height and the greater number of cutting teeth on the periphery of the central slug adversely combine with the difficulty of cutting a chip which is extremely thin in a radial direction as to cause the cutter as a whole to deflect radially. This phenomenon is particularly true with smaller machine tools (such as magnetic base and other portable drill units) and less apparent with more rigid and non-yielding machine tools (such as drill presses, lathes, milling machines, etc.). However, when the cutter deflects radially, the bore of the cutter pilots the cutter on the central slug rather than machining the slug to its desired small finish diameter and forces the outer periphery of the cutter to revolve about the eccentric axis  $A_2$  rather than about the central axis  $A_1$ . This results in an oversized hole in the workpiece and blinding of the central slug within the cutter bore. A feed rate of less than 0.05 mm per tooth is impractical and inefficient. At the same time it requires an extremely sharp cutting edge to cut a chip from the periphery of the central slug having a radial thickness of less than about 0.025 mm when cutting through metal, such as mild steel. The cutting edges of even an extremely sharp cutter will become sufficiently blunted in even mild steel after cutting through 50 or 75 mm as to be unable to cut a chip having substantial height and a radial thickness of less than about 0.025 mm. When cutting metals which work harden, such as some stainless steels, an even higher inside chip load on the wider teeth is required. In view of the above, it has now been determined that as a practical matter the cutter should be designed so that the radial thickness of the chip cut from the periphery of the central slug should be not less than about 0.025 mm.

Therefore, when one-half the number of teeth are cutting chips from the outer peripheral surface of the central slug (teeth 20e, 20f and 20a in Fig. 3) and the eccentricity is about 0.127 mm, the number of teeth on the cutter should not be greater than about eight. On the other hand, if the cutter has as many as twenty teeth and is ground eccentrically so that one-half of the teeth produce a cut on the periphery of the central slug, then the eccentricity should be not less than about 0.254 mm.

The required eccentricity can be held to a minimum while maintaining the necessary radial inside chip load to about 0.025 mm per tooth by radially relieving the inside cutting edge of a number of wider teeth. For example, in the cutter shown in Fig. 3, if the eccentricity is about 0.127 mm and the inner end of tooth 20f is relieved radially so that only teeth 20e and 20a cut on the periphery of the central slug, then the chips cut by each of these two teeth will have a radial thickness of about 0.064 mm. Likewise, if a twenty tooth cutter has the inside edge of every other tooth relieved radially so that only five of the twenty teeth cut on the peripheral surface of the central slug, then each of these five teeth would produce a chip having a radial thickness of about 0.025 mm if the eccentricity were about 0.127 mm. With the same eccentricity, radially relieving every second tooth would double the radial inside chip load and relieving every third tooth would triple the radial inside chip load. As a practical matter, from the standpoint of grinding a cutter on a production machine, it is easier to radially relieve the inner ends of regularly spaced teeth around the entire periphery of the entire cutter rather than determining which half of the teeth are wider and then relieving selected ones of these wider teeth.

It has been found that, if the cutter is used without liquid coolant, the radially inner ends of at least those wider teeth which cut on the outer peripheral surface of the central slug should be radially relieved just behind the inner ends of the cutting edges of these teeth. More specifically, as shown in Fig. 12, these teeth should be radially relieved outwardly as indicated at 38 so as to leave a narrow margin 40 extending circumferentially rearwardly from the inner end of the inner cutting edge 24. The circumferential extent of margins 40 is between 0.25 mm and 1.52 mm, and preferably about 0.38 mm. The relieved portion 38 should extend rearwardly into the next successive gullet 28 and should have a height equal to at least the height of the gullets 28.

It has also been found that any tendency for the cutter to produce an oversize hole can be minimized by grinding the inner cutting edges 24 with a positive side rake angle relative to the outer periphery of the central slug and the outer cutting edges 26 with a zero or negative side rake angle relative to the side wall of the hole being cut. When these edges are so ground, the ability of the wider inner cutting edges to cut a thin chip

from the periphery of the slug is enhanced and, at the same time, the tendency for the outer ends of the outer cutting edges 26 to cut radially outwardly into the side wall of the hole is minimized. In Fig. 12 the outer cutting edges 26 are shown with a negative side rake angle and the inner cutting edges 24 are shown with a positive side rake angle.

#### Claims

- 10 1. An annular hole cutter having a shank adapted to be engaged with a holder for rotation about the central axis of the shank, said shank having an inverted cup-shaped body portion at the lower end thereof, said body portion having an annular side wall provided with a plurality of
- 15 circularly arranged cutting teeth spaced circumferentially around the lower end thereof so that, when the cutter is rotated and advanced into a workpiece, the teeth cut an annular groove
- 20 extending around a central slug within the bore of the cutter side wall, the outer periphery of said shank and the circle defined by the outer periphery of said teeth being concentric to said shank axis to a high degree of accuracy and the
- 25 circle defined by the inner periphery of said teeth being concentric to a high degree of accuracy to a second axis parallel to and offset radially a predetermined distance from said shank axis, whereby the teeth around half of the periphery of
- 30 the side wall are progressively wider than the remaining teeth around the other half of the periphery of the side wall, said second axis being offset radially from the shank axis in an amount such that the radial thickness of the chips cut
- 35 from the peripheral surface of the central slug by

the radially inner edges of the wider teeth is at least 0.025 mm (0.001 inch).

2. A cutter as claimed in claim 1, in which said axes are spaced apart radially so that the radial thickness of the chips cut by the wider teeth is defined by the following equation:

$$t = \frac{2e}{n}$$

- 45 where  $t$  is the radial thickness of the chip,  $n$  is the number of teeth on the cutter and  $e$  is the amount of said offset.

3. A cutter as claimed in claim 1 or 2, in which the radially inner ends of at least the wider teeth which cut chips from the peripheral surface of the central slug are radially relieved to form a narrow margin extending circumferentially rearwardly from the inner ends of their cutting edges.

4. A cutter as claimed in claim 1 or 2, in which the radially inner ends of the cutting edges of some of the wider teeth are radially relieved sufficiently to prevent them from cutting chips from the outer periphery of the central slug.

5. A cutter as claimed in any of claims 1 to 4, in which the radially inner end portions of the cutting edges of the wider teeth are formed with a positive side rake angle and the radially outer end portions of the cutting edges of the teeth are formed with a zero or negative side rake angle.

6. An annular hole cutter constructed substantially as herein described with reference to and as illustrated in Figs. 4 to 12 of the accompanying drawings.